VARIABILITY OF ZOOPLANKTON TOWS IN A SHALLOW ESTUARY

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ABSTRACT

Short-term variability in the zooplankton of a shallow estuary with minimal tidal fluctuations in the northwestern Gulf of Mexico was examined at one station on April 13 through 15, 1976. Densities were estimated from three replicate oblique tows taken every four hours over the 44-hour study period. Counting and subsampling error was not significant compared with replicate tow variability, and replicate tow variability was small compared with the variability among sampling times. Overall densities were large during the night compared to the day and the greatest variability in replicate tows occurred during both sunrise sampling times.

INTRODUCTION

Estuarine systems in the northwestern Gulf of Mexico are frequently characterized by minimal tidal fluctuations and extremely shallow basins. The short-term (hours-days) variability in density estimates from zooplankton tows in other types of estuaries has often been associated with tidal fluctuations and in some cases with the diel vertical movement of organisms in relatively deep bay waters (Hopkins 1963, Pillai and Pillai 1973, Sameoto 1975, Trinast 1975, Lee and McAlice 1979, Youngbluth 1980). Although the number of zooplankton studies conducted in coastal estuaries of the northwestern Gulf has increased steadily in the past 2 decades (Matthews 1980), work on sampling variability in these areas has not been published. This study was designed to examine the extent of short-term variability of density estimates from zooplankton tows taken in West Bay, Texas (maximum depth of 1.8 m), and to determine the relative importance of factors contributing to this variability.

The short-term variability in results obtained from zooplankton net tows taken at a fixed station can be divided into three components each with several possible causal factors:

1) Variability over a short period of time (hours-days).
   a. Movement of water past a sampling point introducing new populations (tidal flow, currents).
   b. Vertical migration of organisms if tows do not cover the entire water column.
   c. Biological changes in populations (growth, mortality).
   d. Differential avoidance of nets due to varying light intensities.

Contributions in Marine Science, Vol. 24, pp. 81-92, 1981.

2) Variability at one specific time.
   a. Small scale horizontal patchiness.
   b. Vertical stratification of the zooplankton combined with variations in sampling depth.
   c. Flowmeter inaccuracies.
   d. Variability in net clogging.
3) Variability introduced in the laboratory.
   a. Subsampling error.
   b. Counting error.

The sampling scheme and data analysis used in this study were designed to examine the relative importance of these three error components. Causal factors for the observed variability are considered and methods for reducing this variability are suggested.

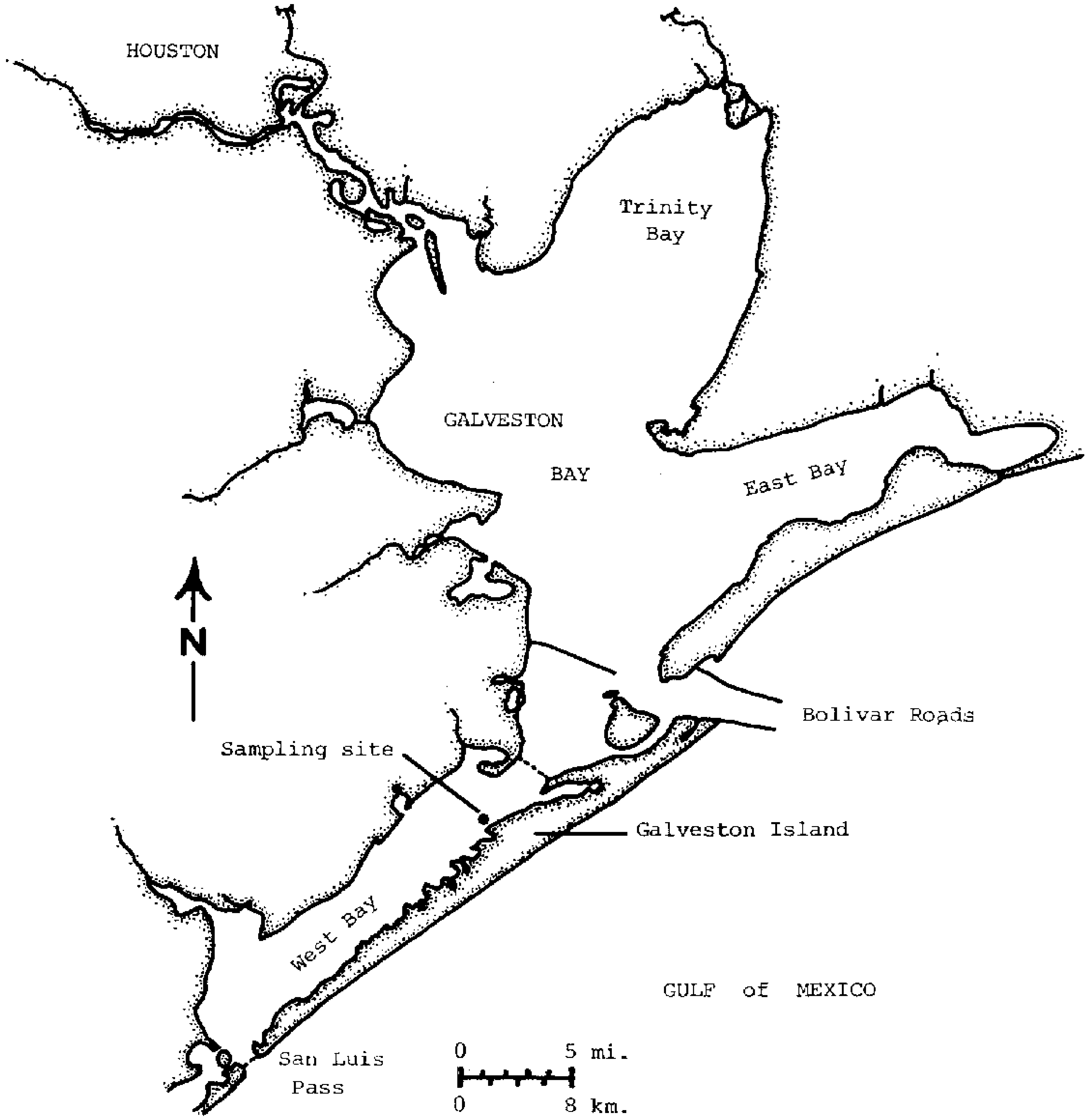

FIG. 1. Map of the study area.

MATERIALS AND METHODS

A single sampling station was established in West Bay, a shallow polyhaline bay in the Galveston Bay System (Fig. 1). The station was located midway between San Luis Pass and Bolivar Roads, the two major inlets connecting the bay system with the Gulf of Mexico. Tidal fluctuations in this area are small, ranging from 0.3 to 0.5 m (Pullen, Trent, and Adams 1971).

Intensive zooplankton sampling was conducted over a 44-hour period from April 13 to 15, 1976. Three replicate oblique tows were taken every 4 hours over the study period (36 tows). The 12 sampling times were numbered sequentially beginning with sampling time 1 at 2100 hours on April 13 and ending with sampling time 12 at 1700 hours on April 15. Each set of three tows was taken within 45 minutes of the recorded sampling time. The sampling gear consisted of a 0.5 m conical net made of 241 μm mesh Nitex. A General Oceanics digital flowmeter was mounted in the center of the net mouth. Five-minute oblique tows were taken at approximately 1 m/sec from a 4.9-m (16-ft) skiff, and an average of 36 m^3 of water was filtered per tow. During the tows the net, lowered and raised by hand, reached to within 0.5 m of the bottom. Tows were taken in a wide circle to eliminate any influence of propeller turbulence from the outboard engine. The depth of the water at our station was approximately 1.8 m at mean tide level.

Water temperature, salinity, and turbidity were measured from surface samples taken at each of the 12 sampling times. Tide data were obtained from hourly readings taken by the U.S. Weather Bureau at Pier 21 in Galveston Channel and were corrected with a lag time of 2.25 hours for the distance to our sampling station. Data on wind speed were obtained from measurements recorded at the Galveston Airport Weather Station located approximately 7 km from our sampling site.

A 5-ml Hensen-Stempel pipet was used in the laboratory to take three subsamples from each sample collected. The volumes of the samples were adjusted with tap water according to the amount of water filtered during the tow, so that every 5-ml subsample represented 0.25 m^3 of water filtered. The 108 subsamples were analyzed in a random order to prevent a biased count of individuals. Densities of four categories of organisms were recorded: total zooplankton, *Acartia tonsa*, *Pseudodiaptomus coronatus*, and barnacle nauplii (*Balanus* spp.). Copepodid stages were combined with adults in all counts of copepods. Few copepod nauplii were captured in our net.

A nested analysis of variance (Hicks 1973) on log transformed densities was used to analyze the data. The log transformation appeared to adequately normalize the densities and reduce the positive relationship between the mean and the variance present in the untransformed data. Variability among the 12 sampling times was tested with replicate tow variability (tows taken at one time), and replicate tow variability was tested with the laboratory variability. Duncan's multiple range test was used to compare mean densities at the 12 sampling times. Confidence intervals based on subsampling and coefficients of variation were calculated from untransformed data.

RESULTS

The variability among the 12 sampling times was high in relation to the replicate tow variability. F values calculated for sampling times in the analyses of variance for all four categories of organisms were highly significant (Table 1). Over the sampling period large numbers of organisms were consistently captured during the night at high tide, and relatively few organisms were caught during the day at low tide. This pattern was exhibited to various extents by all groups of organisms examined (Fig. 2 and 3). Mean densities for total zooplankton, *Acartia tonsa*, and *Pseudodiaptomus coronatus* from the three daylight time periods on April 14 were significantly lower (5% level) than those of all other time periods (Table 2). Differences among mean densities

TABLE 1

The analysis of variance results calculated from log transformed densities for the four categories of organisms examined.

Source of variation	df	SS	F	P
Total Zooplankton				
Total	107	75.49		
Sampling times	11	60.54	8.96	≤ 0.0001
Replicate tows	24	14.74	214.02	≤ 0.0001
Laboratory error	72	0.21		
Acartia tonsa				
Total	107	96.89		
Sampling times	11	73.23	6.83	≤ 0.0001
Replicate tows	24	23.40	270.28	≤ 0.0001
Laboratory error	72	0.26		
Barnacle nauplii				
Total	107	108.45		
Sampling times	11	99.18	31.73	≤ 0.0001
Replicate tows	24	6.82	8.35	≤ 0.0001
Laboratory error	72	2.49		
Pseudodiaptomus coronatus				
Total	107	284.20		
Sampling times	11	243.83	14.88	≤ 0.0001
Replicate tows	24	35.74	23.19	≤ 0.0001
Laboratory error	72	4.62		

of barnacle nauplii for the 12 time periods were more complex. Although small variations in surface water temperature were apparent, surface temperatures and salinities were generally similar throughout the study period and did not appear to be related to changes in density of the organisms (Table 3). Increased densities of organisms during the daylight hours of April 15 compared to the daylight hours of April 14 coincided with increased wind speed and turbidity.

Replicate tow variability (variability within time periods) was high in relation to the laboratory error. Analysis of variance results for all four categories of organisms examined indicated highly significant F values for replicate tows

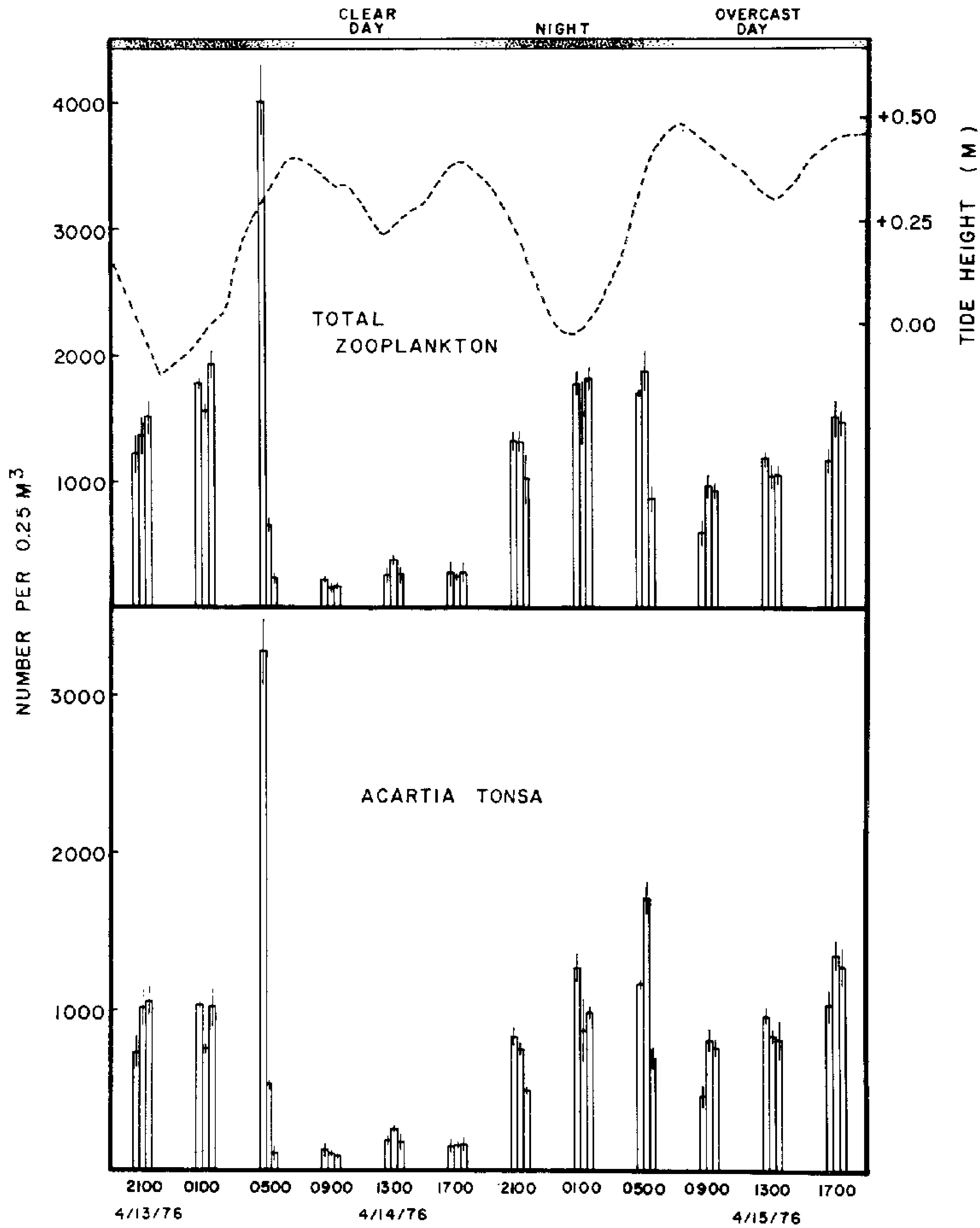

FIG. 2. Densities of total zooplankton and *Acartia tonsa*. Bars represent mean densities, calculated from three subsamples, for each tow taken over the 2-day sampling period. Within each sampling time, the means are arranged in the order in which the tows were taken. The vertical line through each bar indicates the 95% confidence interval calculated from the three subsamples. The dashed line represents the tidal level.

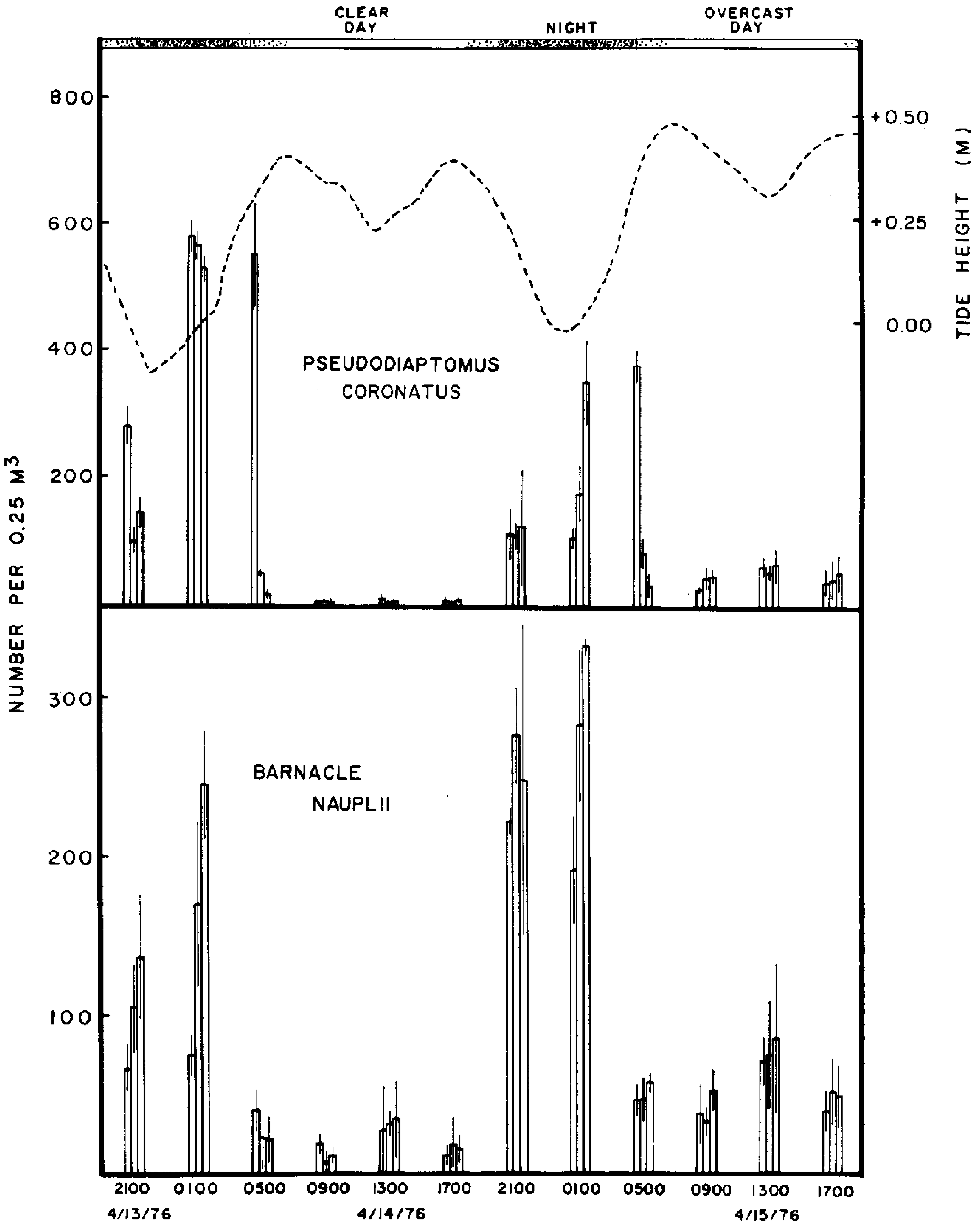

FIG. 3. Densities of *Pseudodiaptomus coronatus* and barnacle nauplii. Graphed as in Fig. 2.

(Table 1). Coefficients of variation calculated from the three replicate tows taken at each sampling time ranged from 3.4 to 126.5% for total zooplankton, 3.0 to 133.2% for *Acartia tonsa*, 4.7 to 147.0% for *Pseudodiaptomus coronatus*, and from 10.5 to 53.0% for barnacle nauplii (Table 4). The highest coefficients for *A. tonsa* and *P. coronatus* occurred near sunrise at 0500 hours on both days. Confidence intervals (95%) calculated from log transformed densities

TABLE 2

Duncan's multiple range test results comparing means from the 12 sampling times for the four categories of organisms examined. The replicate tow error term from the analysis of variance was used in this analysis. Sampling times are arranged in descending order on the basis of mean density. Sampling times connected by a line cannot be statistically distinguished at the 5% significance level.

Sampling sequence number	1	2	3	4	5	6	7	8	9	10	11	12
Sampling time	2100	0100	0500	0900	1300	1700	2100	0100	0500	0900	1300	1700
					4-14-76						4-15-76	
Total zooplankton												
	2	8	9	12	1	7	11	3	10	5	6	4
Acartia tonsa												
	12	9	8	1	2	11	7	10	3	5	6	4
Barnacle nauplii												
	8	7	2	1	11	9	12	10	5	3	6	4
Pseudodiaptomus cornatus												
	2	8	1	7	9	3	11	12	10	6	5	4

of total zooplankton for 10 of the sampling times (omitting the 0500 hour tows) ranged from 92–108% of the mean to 50–193% of the mean (n=3). The 95% confidence intervals were large for the 0500 hr tows on April 14 (1–1870% of the mean) and April 15 (33–269%).

Variability in zooplankton density estimates introduced in the laboratory was small in relation to the replicate tow variability. Laboratory error remained insignificant even when time period 3 (highest replicate tow variability) was eliminated and the analysis of variance was recalculated. The coefficients of variation for total zooplankton from the three subsamples taken from each sample ranged from 0.4% to 14.3% with a mean of 4.4% (SD= 3.0, n= 36). Since laboratory error could be attributed to subsampling or counting error, the organisms in six subsamples were counted twice. Subsampling error appeared to be approximately 3.5 times as important as counting error.

TABLE 3

Temperature, salinity, and turbidity measurements from surface water samples for the 12 sampling times. Surface wind speeds are also indicated.

Sampling time	Temperature (°C)	Salinity (ppt)	Turbidity (% trans.)	Wind speed (km/hr)
4-13-76				
2100	24.1	24.5	92	26
4-14-76				
0100	23.9	24.0	92	23
0500	23.0	24.0	92	21
0900	23.2	24.0	92	23
1300	24.4	24.0	91	24
1700	25.1	24.5	91	26
2100	24.1	24.5	93	26
4-15-76				
0100	24.0	25.0	94	27
0500	23.3	24.5	90	24
0900	23.4	24.5	88	26
1300	23.6	25.0	82	34
1700	23.5	25.0	81	37

DISCUSSION

The overall results indicated that relatively little variability in our density estimates could be attributed to subsampling and counting error. Similar conclusions have been made by Wiebe, Grice, and Hoagland (1973) and by Lee and McAlice (1979). Subsampling with the Hensen-Stempel pipet appears to be reliable for small (approximately 1 mm or less animals with the possible exception of high density organisms such as shelled molluscs. Since this subsampling method did not introduce any appreciable variability into our results, replicate subsampling of samples with a similar species composition is probably unnecessary.

Although the pooled variability from replicate tows (those taken at approximately the same time) was high in relation to laboratory error, it was relatively low compared to the variability among sampling times. Despite differences in sampling designs and methods of analysis, the replicate tow variability as indicated by coefficients of variation and 95% confidence intervals for 11 of the 12 sampling times (excluding time period 3) is comparable to other published data on estuarine sampling variability (Hopkins 1963, Carpenter, Anderson, and

TABLE 4

Coefficients of variation (%) for the 12 sampling times. Values were calculated from mean densities (untransformed data) for the three tows taken during each time period. C.V. = SD(100)/$\overline{X}$

Sampling time	Total zooplankton	*Acartia tonsa*	Barnacle nauplii	*Pseudodiaptomus coronatus*
4-13-76				
2100	10.6	17.7	34.2	54.4
4-14-76				
0100	10.5	17.9	52.2	4.7
0500	126.5	133.2	37.7	147.0
0900	18.8	18.5	53.0	19.9
1300	14.6	21.1	10.5	42.6
1700	3.4	3.0	23.2	21.1
2100	13.7	25.0	10.9	5.8
4-15-76				
0100	8.4	19.3	26.7	60.4
0500	36.4	42.2	13.6	116.2
0900	24.9	27.4	26.4	31.1
1300	6.8	9.0	10.3	9.2
1700	13.6	13.8	13.6	18.2

Peck 1974, Sameoto 1975, Lee and McAlice 1979). Most of the variability among replicate samples in other studies has generally been attributed to the small scale patchy distribution of organisms, which also may have been important in our samples. The greatest variability among the 12 sets of three replicate tows in our study, however, occurred near sunrise at 0500 hours. The high variability in these samples could be explained by the downward movement of organisms out of the range of our net during the time needed to make the three tows.

Most of the variability among our 12 sampling times can be attributed to the diel vertical migration of organisms or to the movement of large patches of zooplankton past the sampling area due to tidal flow. Because tidal changes coincided with changes in daylight during our 2-day sampling period, these factors are confounded. Although the effect of tides on zooplankton sampling results has generally been regarded as important in estuaries (Hopkins 1963, Trinast 1975, Lee and McAlice 1979), tidal fluctuations in most of West Bay are small and are probably of little significance. Evidence from our study strongly suggests that changes in the vertical distribution of organisms were a major factor influencing the variability among sampling times. The high zooplankton densities observed during the night tows and the low densities during the day tows were consistent with the typical diel migratory pattern exhibited by many zooplanktonic organisms. *Acartia tonsa, Pseudodiaptomus coronatus,* and barnacle nauplii made up approximately 90% of the organisms captured in this study, and densities of all three groups were highest during night tows. Other studies in the Galveston Bay System (McAden 1977), the coastal waters off Galveston (Allison 1967), and in other estuarine areas (Jacobs 1961, Youngbluth 1980) have indicated that *A. tonsa* undergoes typical diel migrations. Although evidence for typical migratory behavior in barnacle nauplii is conflicting, McAden (1977) concluded that these organisms also migrated towards the surface at night. The large day-night differences in the density of *P. coronatus* also support the importance of diel migrations in our samples. This species was rarely captured in our daytime tows. *Pseudodiaptomus* is known to be a strong vertical migrator (Grice 1953, Jacobs 1961, Pillai and Pillai 1973), and it has been suggested by Grice (1953) and Jacobs (1961) that copepodids and adults of *P. coronatus* may be demersal, in which case they occupy the water column during the night and become associated with a substrate during the day.

Zooplankton densities were also significantly higher during the daylight hours of April 15 compared to this same time period on April 14, although tidal heights were similar on both days. On April 14 the sky was clear and winds were relatively calm. On April 15, however, the sky was overcast and the wind increased vertical mixing in the water column as evidenced by the increase in turbidity. Both of these factors, an overcast sky and an increase in vertical mixing, would tend to prevent a strong migration away from the surface during the daylight hours of April 15. The extent of vertical mixing in the water column may be especially important in relation to the daytime catch of *P. coronatus*. Perry (1970) found in a Mississippi estuarine system, when sampling during the day, that most of her catch of *P. coronatus* was in shallow turbulent waters.

Although our sampling was limited to a 2-day period in the spring, the large fluctuations observed in zooplankton densities should be considered when interpreting other data obtained through similar sampling methods. Total zooplankton densities on both nights were similar, but they were approximately 6 times greater than daytime densities on April 14. Daytime densities on April 15 were 3 to 5 times greater than on April 14. This day-to-day variability may be especially important and apparent seasonal or spatial variations of these magnitudes could be attributed to short-term sampling variability.

To improve methods of estimating zooplankton densities in shallow estuaries, light and weather conditions should be considered. The vertical migratory behavior of the zooplankton apparently influences sampling results even in extremely shallow estuaries. To obtain comparable density estimates from net tows, an effort should be made to avoid sampling near sunrise or sunset. Day tows should not be compared to night tows, and sampling should be conducted under similar wind and sky conditions if possible. The most accurate method of estimating zooplankton densities will involve obtaining at least one oblique tow during the day and one during the night from each station. Night sampling in these estuarine systems is difficult however, and may not be practical. The use of a pump to sample the entire water column during the day is another alternative. Pump sampling, however, is only adequate for the smaller zooplanktonic organisms and will underestimate densities of demersal zooplankton.

ACKNOWLEDGMENTS

We would like to thank Gerald P. Livingston and Dr. R. K. Steinhorst for their help with some of the statistics. We would also like to thank Dr. E. T. Park and Dr. D. V. Aldrich for reading portions of the manuscript and suggesting changes.

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